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WATERSHED MANAGEMENT PROBLEMS AND OPPORTUNITIES FOR THE COLORADO FRONT RANGE PONDEROSA PINE ZONE: The Status of Our Knowledge

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Abstract

The east flank of the Continental Divide consists largely of open timber stands and grasslands. Soils erode easily after abuse. Precipitation ranges from 15 to 20 inches, about two-thirds from high-intensity storms from April to September.

Guidelines are provided for maintaining satisfactory watershed conditions. The 3- to 5-inch water yields are comparatively small in contrast to yields of 12 to 25 inches from the high-altitude subalpine forests, but are important to development along the Front Range. Watershed management practices can be expected to provide practical alternatives for increasing water supplies.

Keywords: Coniferous forest, forest management, range management, vegetation effects, ponderosa pine zone, watershed management, land use planning.

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Howard L. Gary

The rapid and continuing economic expansion along the east slope of the southern range of the Rocky Mountains, with attendant greater use of resources, has complicated management of the Front Range watersheds.

This Paper is one of a series for the vegetation zones in the land areas for which the Rocky Mountain Forest and Range Experiment Station has research responsibility for resource management. Its purposes are to (1) summarize past studies and evaluate the status of watershed management knowledge for the Colorado Front Range pine type, and (2) indicate to what extent we are able to recommend management practices to improve water yield and still maintain acceptable quality and quantity of water and other wildland resources.

Regional Description

The Colorado Front Range, generally regarded as the eastern foothills region of the Rocky Mountains, extends from roughly southern Wyoming to Canon City, Colorado. The region is bounded on the east by plains; on the west it reaches to the crest of the Continental Divide. The low-elevation (6,000 to 9,000 ft) forests and grasslands are generally termed the ponderosa pine zone. Chief characteristics are its infertile and potentially unstable soils, and sparse tree cover. Moisture is provided mostly in late spring and midsummer by afternoon thunderstorms.

Timber cutting started more than 100 years ago. Commercially valuable tree species above 7,000 ft elevation are ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*), Douglas-fir (*Pseudotsuga menziesii*), and some Engelmann spruce (*Picea engelmannii*). Much of the forest cover is a residual of old growth passed over in earlier cuttings, mixed with patchy stands of second growth. Aspen (*Populus tremuloides*) is also an important component in many young stands, particularly after fire.

Grazing by livestock is also a major land use in certain areas. In 1950, approximately 300,000 head of cattle were grazed, some yearlong and some only a few months. Many of the valleys were farmed in the early 1900's, but have since been abandoned because of low rainfall and erosion problems.

Today, recreation use and residential development in the Front Range probably have highest impacts.

Physiography

Land features along the Front Range include ridges, mountain slopes, steep rocky canyons, foothills, narrow mountain valleys, and large openings or parks. Geologic features of this area are summarized by Marcus (1973). Soils, for the most part, developed from coarse granite rocks, alluvial deposits, sandstones, limestones, and quartzite.[2]

The most stable soils are those developed from limestone, while the most unstable are those derived from granite bedrock. The limestone and deep granite alluvium soils have the highest productive capacity, while those from granite bedrock are the least fertile and most erosive. The latter soils occur over about 90 percent of the Front Range (USDA FS 1949). Since they occupy extensive areas, much additional work is needed before we can manage them to their potential. Wet meadows cover about 2 percent of the area, and are the only highly productive grazing lands in the region.

Vegetation

As a result of the relatively abrupt ascent from the plains, the several vegetation and life zones are usually restricted to well-defined

[2]*Retzer, John L. 1949. Soils and physical conditions of Manitou Experimental Forest. 35 p. (Unpublished report on file at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

horizontal belts. On the Western Slope of the Rockies, the slopes are more gradual and cover types overlap over a considerable horizontal distance. Costello (1964) points out that the vegetation zones are also conditioned by geology, physiography, and climate, and that past grazing, logging, and mining will have a continuing effect on the vegetation.

The ponderosa pine type covers approximately 4 million acres in the Front Range of the Colorado Rockies; Statewide it is distributed principally from the Wyoming line to Trinidad, west to Mesa Verde, and north to the Uncompahgre Plateau (Costello 1964). Alexander (1974) summarized the status of our knowledge in timber management of the ponderosa pine type. The type occurs on ridges and slopes at elevations varying from 6,000 ft in the foothills to 8,500 to 9,000 ft in the mountains (fig. 1). The open ponderosa pine stands on south and west

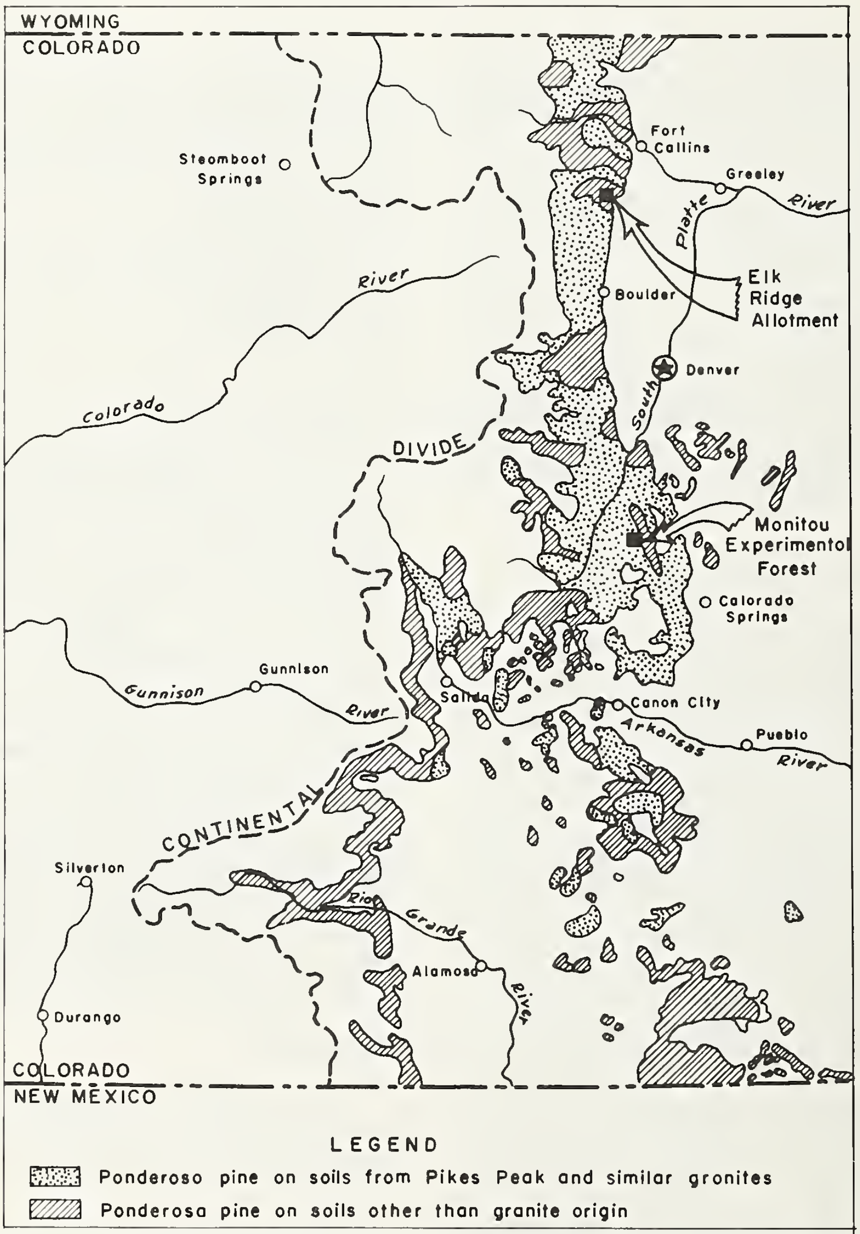

Figure 1.—Distribution of the ponderosa pine type along the Front Range of the Colorado Rockies in relation to soil origin.

slopes permit an abundance of light and the development of herbaceous understory (fig. 2). Grasslands, devoid of trees, are frequent. Meadows and streambanks often support luxuriant vegetation. On the north slopes, under denser Douglas-fir and Engelmann spruce, herbaceous plants are scarce. Shrub and broad-leaved tree communities are also common throughout the pine zone. Some of the communities represent stages in secondary succession following fires and other disturbances.

Cover for the Missouri Gulch watershed (elevations from 7,500 to 9,300 ft), on the Manitou Experimental Forest, is characteristic of much of the pine zone. The areas of plant-cover types reported by Berndt (1960) were as follows:

	Area *(Acres)*	Proportion of total *(Percent)*
Lodgepole pine —Engelmann spruce	1,119	24.3
Ponderosa pine —Douglas-fir	1,372	29.8
Quaking aspen	392	8.5
Mixture	966	21.0
Brush and grass	352	7.7
Erosion pavement	316	6.9
Bare rock	83	1.8

Climate

The climate of the region is typically sub-

Figure 2.—Panoramas typical of the Front Range pine type: **A**, the North Fork of the Little Thompson watershed; **B**, the Manitou Experimental ranges.

humid, with wide diurnal and annual temperature ranges and great variation in the occurrence and distribution of rainfall. The greatest single factor controlling the climate is the Rocky Mountain range, which runs somewhat normal to the prevailing westerlies and the northwesterlies during the winter and the southeasterlies during the summer. Precipitation may be in the form of snow from late September through May, but snows commonly melt from the south exposures and valleys within days. The shallow snowpacks at the higher elevations and on the protected north exposures generally disappear by mid-May.

Precipitation through the Front Range pine zone probably averages between 15 and 20 inches. Average precipitation amounts for two centrally located and representative stations within the pine zone are:

	Estes Park	Manitou Experimental Headquarters
Elevation, ft	7,525	7,740
Years of record used	46	21
Average annual precipitation, inches	16.5	15.4

Precipitation at Estes Park has ranged from a low of 9.43 inches in 1939 to a high of 32.47 inches in 1946. The precipitation and mild temperatures are normally well distributed for plant growth throughout most of the Front Range zone (fig. 3).

About two-thirds of the annual precipitation occurs in the April-to-September growing season, and thus accounts for the abundance of grass over much of the area. Most of the summer precipitation comes in thunderstorms of varying intensities. A study of 25 significant summer storms on the Missouri Gulch watershed from 1940 to 1949 showed the highest rainfall intensity for a 10-minute period to be 4.5 inches per hour (USDA FS 1949). The storms came from all directions and during all months of the summer season:

Months	Number of storms
May	1
June	2
July	15
August	6
September	1

The high-intensity storms are most common along the more exposed and steep slopes in the Front Range pine zone. The placement of the highest rainfall-frequency values will depend on the degree of exposure to moisture-bearing wind, steepness of the slope, and other orographic factors. The possibility of high-intensity storms should therefore be considered in all land treatment programs.

The potential water balance, computed by the procedures outlined by Thornthwaite and Mather (1957), is shown in figure 4 for the Missouri Gulch watershed. The values indicate that annual precipitation is in excess of potential evapotranspiration (ET) only during a portion of the year. The moisture regime is characterized by a moisture deficit when ET depletes soil-moisture storage. As a result, the streams originating in this climate are usually intermittent, and flow only during the late fall, winter, and spring. Depending on the frequency of summer thunderstorms, streamflow may be prolonged during some years.

Floods

The Montane Zone has had a long history of intensive rainfall and infrequent but major floods (Follansbee and Jones 1922, Follansbee and Sawyer 1948, Vaudrey 1960, Matthai 1969, Hansen 1973). Flooding can result from high-intensity summer rainfall, chiefly below 7,000 ft and extending eastward from the foothills for a distance of about 50 miles. Such storms are confined to a very small area and last for a short time. The most devastating floods usually occur in May or June from upslope storms in which precipitation can vary from approximately 2 to an extreme 20 inches over a period of 3 to 5 days. Although the rate of precipitation is typically not heavy by meteorological criteria, the large quantities of long-duration, steady, widespread rainfall make such storms a persistent threat to development and land use along the Front Range.

Above 7,000 ft most of the precipitation from spring storms falls as snow, which can attain depths of 4 ft or more. The snowfall retards runoff, but as Hansen (1973) points out, the potential for landsliding is increased. Thus rainfall and flooding in the Front Range produce significant geologic as well as hydrologic effects. Although small scale in terms of the overall geologic setting, these effects may be uncontrollable once they are set in motion.

Hansen (1973) found that geologic processes triggered by the May 5-6, 1973, storm in the greater Denver area "were intensified in places where the natural regimen has been altered by man." As the Front Range becomes increasingly urbanized, the incompatibilities between natural processes and people will continue to cause problems. Accordingly, careful land use planning is essential if needless risk to lives and

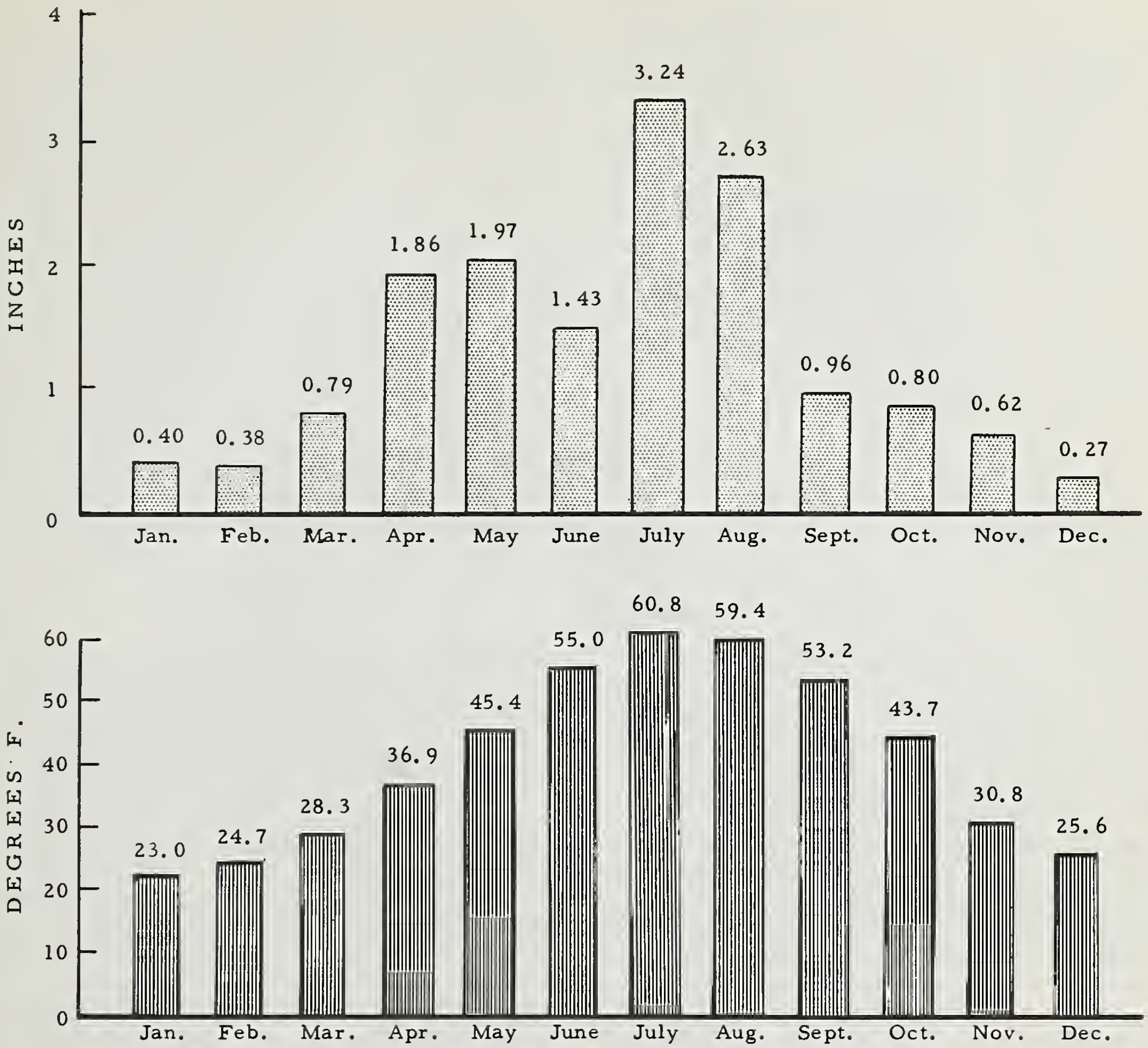

Figure 3.—Monthly mean precipitation (1937-58) and temperature (1942-58) for the Manitou Experimental Forest Headquarters (Berndt 1960).

property and damage to the environment are to be minimized.

Precipitation-Vegetation Interactions

An important factor affecting the disposition of precipitation is the relatively thin soil mantle over most of the Front Range pine zone. One land management problem, therefore, is to seek ways to maintain and improve the hydrologic functioning of the soil mantle. A part of the general problem and the only factor easily altered is the vegetation cover. The specific problem appears to be, "What are the best combinations of soil type and amount of either tree, shrub, or grass cover (and perhaps mechanical structures) to control overland flow, soil erosion, and maintain high quality water yield?" Another aspect of the problem is how to increase water yields or alter the timing of streamflow. Some of the earlier studies of precipitation-vegetation interactions that influence soil protection and water yield are discussed under the headings of Interception, Litter, and Site Requirements.

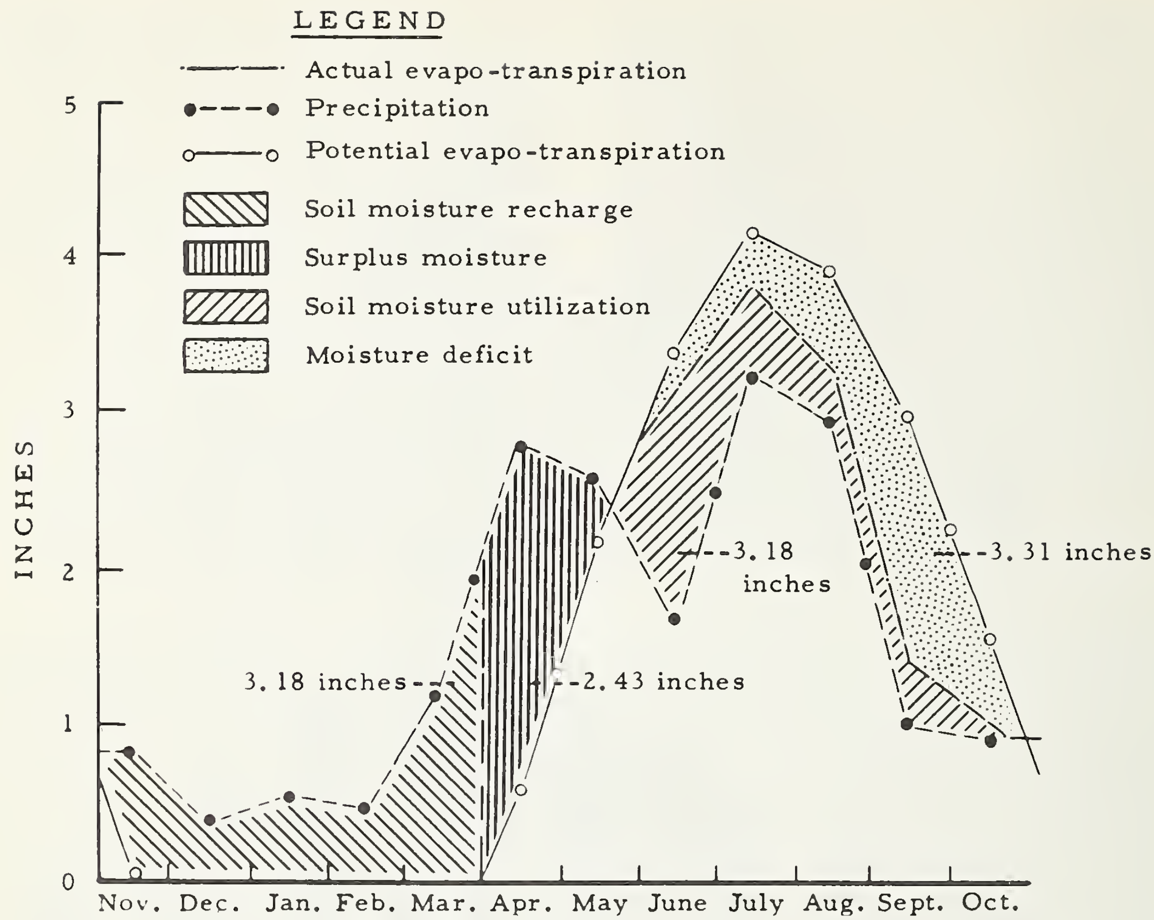

Figure 4.—Potential water balance for the Missouri Gulch watershed (Berndt 1960).

Interception

Part of the precipitation on watersheds is intercepted by the canopies of trees and grasses. Some of the intercepted precipitation eventually reaches the ground, and some is lost by evaporation from the canopies. In an early study of interception in the ponderosa pine in Colorado, Johnson (1942) concluded that an average of 81.4 percent of the total precipitation reached the ground under tree crowns. For heavier precipitation and larger trees in California, Rowe and Hendrick (1951) reported losses of 9.6 percent for snow and 13.6 percent for rainstorms. A loss of about 15 percent of the interception storage has been reported for dense grassy vegetation (Burgy and Pomeroy 1958). In the Colorado study, about 0.03 to 0.05 inch of precipitation was required to saturate the forest canopy in each storm; practically all of the subsequent rainfall reached the ground. Johnson (1942) concluded that interception of snow by tree crowns was quite similar in magnitude to the interception of rain, at least for the Front Range pine zone.

To gain additional knowledge of interception losses, Berndt (1961) studied how logging treatments and the resulting canopy reduction might influence snow accumulation in ponderosa pine-Douglas-fir stands on the Front Range. His 2-year study was in a National Forest timber sale about 35 miles northwest of Colorado Springs, Colorado, at an elevation of about 8,500 ft. Analysis of maximum snowpacks disclosed that snow accumulation after timber cutting increased significantly only on the commercially clearcut plots. Both intensities of cutting increased spring melt rates, but snow disappeared from all plots at nearly the same time. Similar results were observed by Wilm and Dunford (1948) in the subalpine zone of central Colorado.

Hoover and Leaf (1967) found no evidence that increased snow in openings was caused primarily by decreased interception loss; total snow on their study watershed (Fool Creek, Fraser Experimental Forest) was similar before and after strip-cutting treatments. They stated that "while total snow catch remained the same, it is distributed differently over the watershed." This study and others in subalpine forest have conclusively shown that the aerodynamic effect on snow distribution, rather than reduced interception loss, is the major cause of increased snow in openings. This work is reviewed in depth by Leaf (1975).

For precipitation in the form of rain, Croft (1961), and other workers, point out that it must not be assumed that removal of vegetation would result in decreased interception and increased water savings; the soil mantle may be wet only a few inches and the additional water lost by evaporation.

Litter

Retention of a portion of the rain and snow in the litter on the forest floor also affects the moisture supply to the soil and thus subsequent water yield. Litter accumulation is highly variable in the Colorado Front Range. Depending on tree and grass density, litter amounts may range from zero to perhaps 20 tons per acre. Under pole-sized ponderosa pine stands in Arizona, Aldon (1968) observed that moisture retention by litter (about 20 tons per acre) ranged from 7 to 27 percent of the gross precipitation. He found that total moisture retention was directly related to storm size.

In one study, the protective covering of litter was removed from six 1/100-acre plots under small pole stands of ponderosa pine on the Manitou Experimental Forest (fig. 5) to simulate what might happen in a ground fire (Dunford 1954). All plots faced north on 18-percent slopes at an elevation of 7,600 ft. Runoff was measured for 15 years. During a 3-year calibration period prior to litter removal, the runoff ratio of treated/untreated plots averaged 0.73, and for 10 years after litter removal the average ratio was 2.30 (table 1). The ratio ranged from 6.9 the first year after litter removal to a low of 0.7 after 9 years of recovery.

Most watershed management activities will disturb the litter and ground cover to some degree. A study on ponderosa pine lands in Oregon and Washington showed that tractor logging denuded herbaceous and shrubby vegetation an average of 21 percent (Garrison and Rummell 1951). Logging with a cable from a jammer denuded the ground cover 15 percent, and horse logging 12 percent.

Site Requirements

Specific knowledge of precipitation-vegetation interactions necessary for the establishment and maintenance of individual plants of the various timber types are generally lacking for the Front Range pine zone, although much information has been obtained for reseeding deteriorated rangelands (Hull and Johnson 1955). How to recover the productive capacity of the pine lands in terms of wood remains a major job for the land manager. Bates (1923) did some early work on the physiological requirements of the major forest types in the Front Range pine zone. Tarrant (1953) summarized Bates' work on the seedling stage of development for ponderosa pine:

> On dry, hot sites where moisture fluctuates rapidly, ponderosa pine is preeminently adapted—by reason of large seeds which produce large sturdy seedlings and by its prompt deep-rooting characteristic. Considering its xerophytic tendencies, ponderosa pine is an extravagant user of water. Probably this comparative extravagance helps protect the seedlings from excessive heat. Survival is dependent on the roots reaching a layer of soil which does not dry out dangerously through insolation. Ponderosa pine cannot grow in competition with trees, grasses, and herbs that draw heavily on moisture in the upper soil layers. The large moisture demands of ponderosa pine, which grows where precipitation normally is low, can be supplied only in open stands which permit first a deep penetration of the roots and later their extension into a large area of soil.

In contrast, the seedlings of Engelmann spruce, Douglas-fir, lodgepole pine, and limber pine (*Pinus flexilis*) have weak and slowly developing root systems, and require continuous high soil moisture during their first year of development.

Roeser (1940) also studied the relative water utilization and efficiency of water use of seedlings of several forest types in the Front Range pine zone. Seedlings were maintained in containers in sufficient number to simulate complete stocking, yet permit normal development and vigor. After 6 to 10 years, he summarized water use and efficiency. Based on the magnitude of water loss, the species ranked in decreased order as follows: Engelmann spruce, Douglas-fir, pinyon pine (*Pinus edulis*), ponderosa pine, and limber pine. In relative efficiency of water use in production of organic matter, the species ranked as follows: pinyon pine, limber pine, Douglas-fir, Engelmann spruce, and ponderosa pine.

Figure 5.—Ponderosa pine runoff plots before (**A**) and after (**B**) litter removal.

Infiltration, Runoff, and Erosion

Infiltration Capacities

The maximum rate at which water penetrates the soil surface is termed infiltration capacity. This capacity is affected by many factors, but is determined primarily by the noncapillary porosity of the soil surface after it has been thoroughly wetted but not saturated. The greater the diameter of the large pores, the higher the infiltration capacity. Most of the infiltration data for Front Range pine zone are based primarily on infiltrometer runs. Infiltrometers (fig. 6) measure the rate at which sprinkler-applied water soaks into the soil, the rate at which water runs off, and the amount of erosion that might be expected (Dortignac

Table 1.--Average annual surface runoff from ponderosa pine plots before treatment, after removal of litter in 1941, and after tree and litter removal in 1952 (Dunford 1954)

Year	Storms causing runoff	Average seasonal runoff		Ratio: Treated/ control
		Treated	Control	
	No.	*Inches*		
BEFORE TREATMENT:				
1938	13	0.10	0.17	0.6
1939	13	.04	.05	.8
1940	3	.05	.06	.8
AFTER REMOVAL OF LITTER:				
1941	14	1.17	.17	6.9
1942	9	.43	.12	3.6
1943	6	.20	.06	3.3
1944	8	.65	.31	2.1
1945	12	1.05	.59	1.8
1946	6	.11	.10	1.1
1947	13	.36	.23	1.6
1948	6	.06	.07	.9
1949	10	.07	.10	.7
1950	3	.02	.02	1.0
1951	1	([1])	([1])	--
AFTER REMOVAL OF TREES AND LITTER:				
1952	3	.49	.03	16.3

[1]Trace.

1951). The studies were mainly undertaken to isolate and evaluate how vegetation and soil influence infiltration on representative ponderosa pine-bunchgrass ranges.

The general influence of litter on the infiltration capacity of forest soil has long been recognized (Lowdermilk 1930), but specific data are lacking for most soils and in most forest types. In the Front Range ponderosa pine zone, for example, the quantitative influence of forest litter on infiltration was studied as a preliminary step in a comprehensive watershed management research program on the headwaters of the South Platte River (Johnson 1940). In the first reported study undertaken in 1939, Johnson (1940) removed litter and duff (3 inches deep) down to mineral soil from half of his study plots and applied water until a constant infiltration rate for 15 minutes was attained. The time for more or less constant rate of infiltration varied from 45 to 90 minutes. Where litter was undisturbed, infiltration rate was 1.52±0.10 inch; on disturbed plots it was 0.92±0.10 inch.

In a later study near Woodland Park, Colorado, Johnson and Niederhof (1941) directly

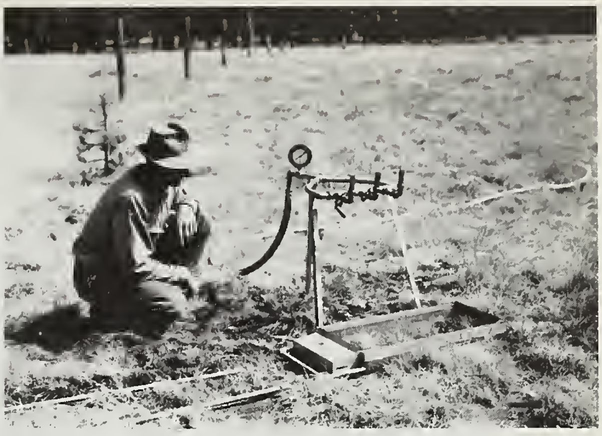

Figure 6.—Rocky Mountain infiltrometer showing rainfall applicator, rainfall trough, and runoff plot.

measured the influence of plant type and rainfall intensity on the rate of surface runoff and erosion, and the effect of individual plant species on the infiltration capacity of the soil. They believed that plant cover such as blue grama (*Bouteloua gracilis*) sod, on soils with naturally high infiltration rates, tends to decrease the rate at which water is able to enter the soil. Turner and Dortignac (1954) reported a similar decrease in absorption under Kentucky bluegrass (*Poa pratensis*) in southwestern Colorado. In the former study, Johnson and Niederhof reported rates of 3 to 9 inches per hour under the mountain bunchgrass type. It was reasoned that the high absorption rates were not due to the effect of the plant cover, but principally to the greater porosity of the soil. Infiltration in bare soil was not measured in the mountain bunchgrass type. The results, though inconclusive in some respects, indicated that certain plant species and associations have more effect than others on infiltration, runoff, and erosion, and that the effectiveness of any species or type is greatly influenced by organic materials and physical soil properties. Litter and porosity of the surface soil were the two measured factors most highly and consistently associated with infiltration rates.

In a later study on the Manitou Experimental Forest and elsewhere in the Colorado Front Range, Dortignac and Love (1960) reported that, on grazed areas, infiltration varies with cover and soil type (fig. 7).

For the Elk Ridge and Lower Elk Ridge Cattle Allotments (mainly above 6,500 ft and below 9,000 ft) in the Roosevelt National Forest, Reid and Love (1951) found that infiltration rates increased with increasing amounts of vegetation

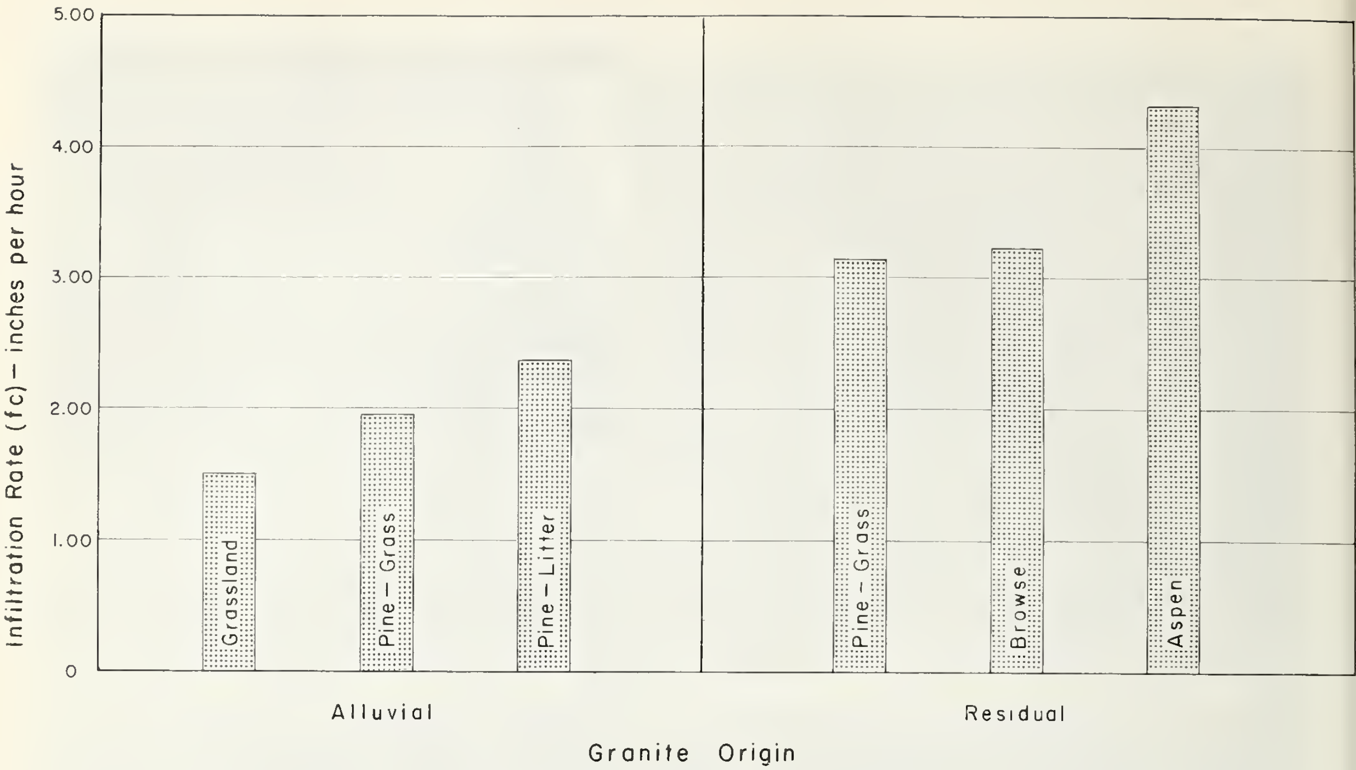

Figure 7.—Average infiltration rates on pastures grazed by cattle at Manitou Experimental Forest (Dortignac and Love 1960).

in the grassland types on soils derived from granite schist. In the timber-grass types on granite schist soils, the infiltration rate was related to total dry weight of litter, which takes the place of herbaceous vegetation in the grassland type as the dominant factor affecting infiltration. The average infiltration on the Elk Ridge Allotments and at Manitou Experimental Forest under similar cover and during the last 20 minutes of 50-minute infiltrometer runs was as follows:

	Elk Ridge	**Manitou**
	(Inches)	
Grassland	1.60	1.50
Pine-grass	2.04	1.94
Pine litter	3.68	2.37

Dortignac and Love (1961) observed that protection from grazing on the Manitou Experimental Forest also increased infiltration. The main effect of cattle grazing was to prevent an increase or recovery of infiltration rates. Litter accumulation in grassland and pine-grass areas grazed by cattle was less than where livestock were excluded.

The upper 2 inches of soil in grazed pastures had a smaller percentage of large non-capillary pores. The differences were reflected in the average infiltration rates obtained under grazing as compared with protection of grazing. The increase in infiltration rate after 14 years' protection from grazing was most pronounced in the grassland:

	1941	**1954**
	(Inches/hr)	
Grassland	1.95	3.26
Pine-grass	1.59	2.60

Surface Erosion

Removal of protective plant cover and soil disturbance caused by road construction, logging, and fire, can accelerate natural erosion processes (fig. 8).

Erosion rates obtained with the infiltrometer have provided the main index of soil erodibility over representative sites in the Front Range. The first erosion surveys in the pine and grassland types at the Manitou Experimental Forest were started in 1936 (Johnson and Niederhof 1941). To determine the influence of plant cover types on surface runoff and erosion, simulated natural rainfall was applied to 132 plots, 1/200

Figure 8.—Unprotected soil showing evidence of accelerated erosion.

acre in size. Collector troughs at the lower ends of the plots conducted surface runoff and eroded material to tanks. The plots were confined to natural parklike areas in an abandoned field, valley bunchgrass, and mountain bunchgrass. To minimize the effect of factors other than vegetation, the average degree of slope was selected within a given type. Slopes of 10 percent were studied in the abandoned field and valley bunchgrass types, and 40 percent in the mountain bunchgrass type. At rainfall intensities of 2 and 4 inches per hour, erosion per ft^3 of runoff was as follows:

Cover type and rainfall intensity	Soil texture (gravel/sand) *(Percent)*	Erosion *(g)*
Abandoned field	66	
2 inches/hr		233
4 inches/hr		173
Valley bunchgrass	76	
2 inches/hr		65
4 inches/hr		67
Mountain bunchgrass	83	
2 inches/hr		113
4 inches/hr		105

Erosion rate was highest on the abandoned fields and smallest on the valley bunchgrass. Variance analysis showed highly significant differences in erosion rates between types. The total volume of eroded material increased with increased intensity of rainfall, but amount of eroded material carried per ft^3 of runoff showed no significant change.

Dortignac and Love (1960) combined the grassland and pine-grass data—the two cover types with the lowest infiltration rates—and obtained the following erosion rates:

Exposed soil *(Percent)*	Elk Ridge Allotment (granite schist residual) *(Lb/acre/inch of runoff)*	Manitou Experimental Forest (granite alluvium)
0- 9	170	96
10-29	440	194
30-69	1,200	289

From the above findings it was concluded that, when on-the-ground organic materials exceed 2 tons per acre, and where exposed soil is

less than 30 percent and large noncapillary pores exceed 20 percent in the upper 2 inches of soil, erosion losses will usually be tolerable and less than 500 pounds per acre per inch of runoff. For some 750 infiltrometer tests conducted at the Manitou Experimental Forest, only two vegetation-soil conditions averaged more than 30 percent bare area. Accordingly, from the standpoint of ground cover and soil protection, watershed conditions sampled in the Manitou portion of the Front Range were generally satisfactory.

In Idaho, Packer (1953) also reported that 70 percent ground cover was required for satisfactory watershed conditions. The erosion rates reported by Dortignac and Love (1960) for the various cover types grazed by cattle (fig. 9) are of little consequence until infiltration capacities (previously shown in figure 7) are exceeded.

Dunford (1954) reported results of another study at the Manitou Experimental Forest where six 1/100-acre plots were used to determine how moderate and heavy grazing affect the amounts of surface water flow and the quantity of soil moved by erosion in the bunchgrass type (fig. 10). Grazing caused an increase in erosion, but not in direct proportion to intensity of use. Average annual erosion from summer storms (fig. 11) ranged from 111 to 163 pounds per acre. During the grazing treatments, 13 storms from 1941 to 1952 were of sufficient size to produce erosion. Average annual depositions were 134,145, and 316 pounds per acre for no grazing, moderate, and heavy grazing, respectively. Only heavy grazing significantly increased erosion, but erosion was measurable in only 8 of the 16 years of study on any plot. Months of greatest soil movement were July and August. It was also noted that erosion tended to occur during periods when large storms followed one another at short intervals. From larger grazing studies at Manitou, Johnson (1953) reported that moderate grazing was most efficient from the standpoint of economic returns in beef production. An additional watershed benefit is that surface runoff and erosion are controlled under moderate grazing.

On six plots of similar size and arrangement

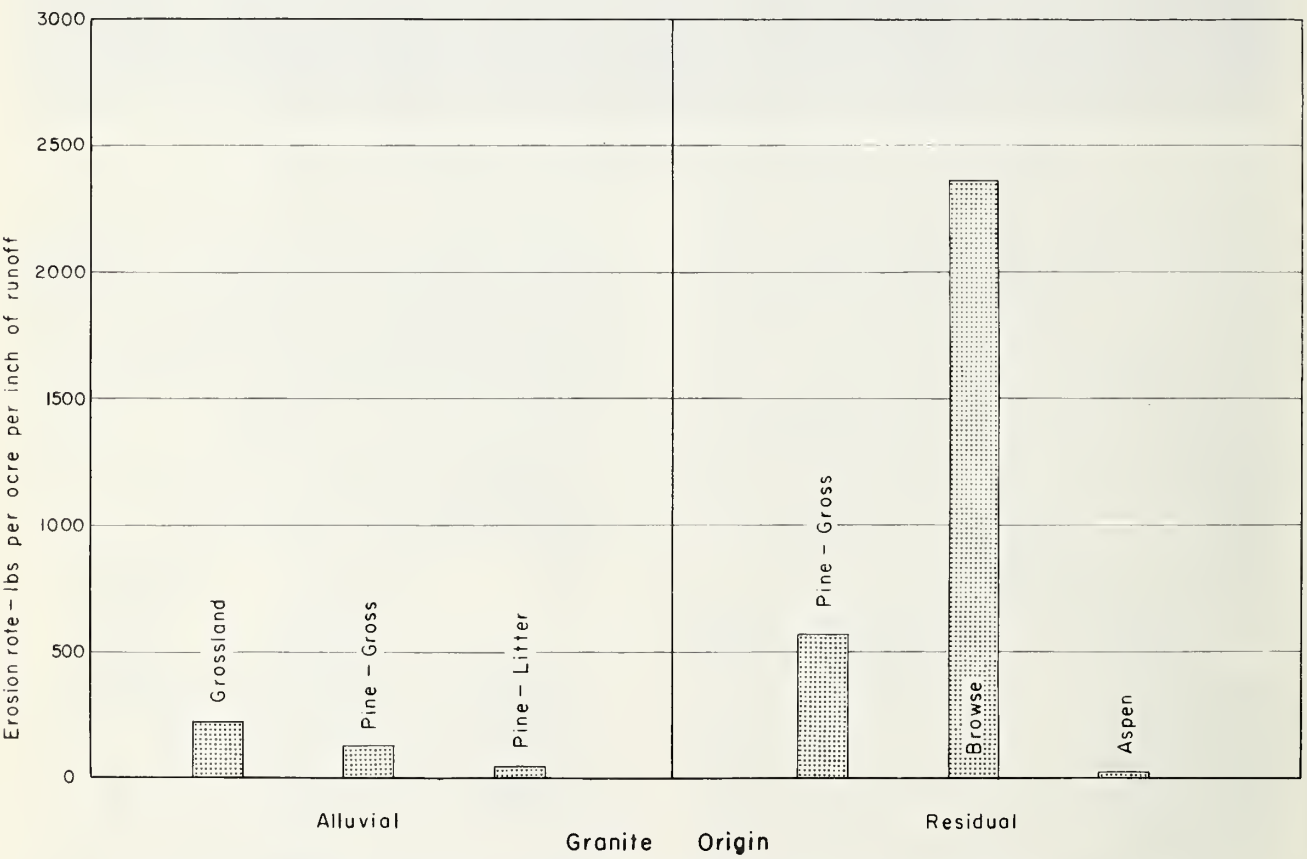

Figure 9.—Average erosion rates on pastures grazed by cattle at Manitou Experimental Forest (Dortignac and Love 1960).

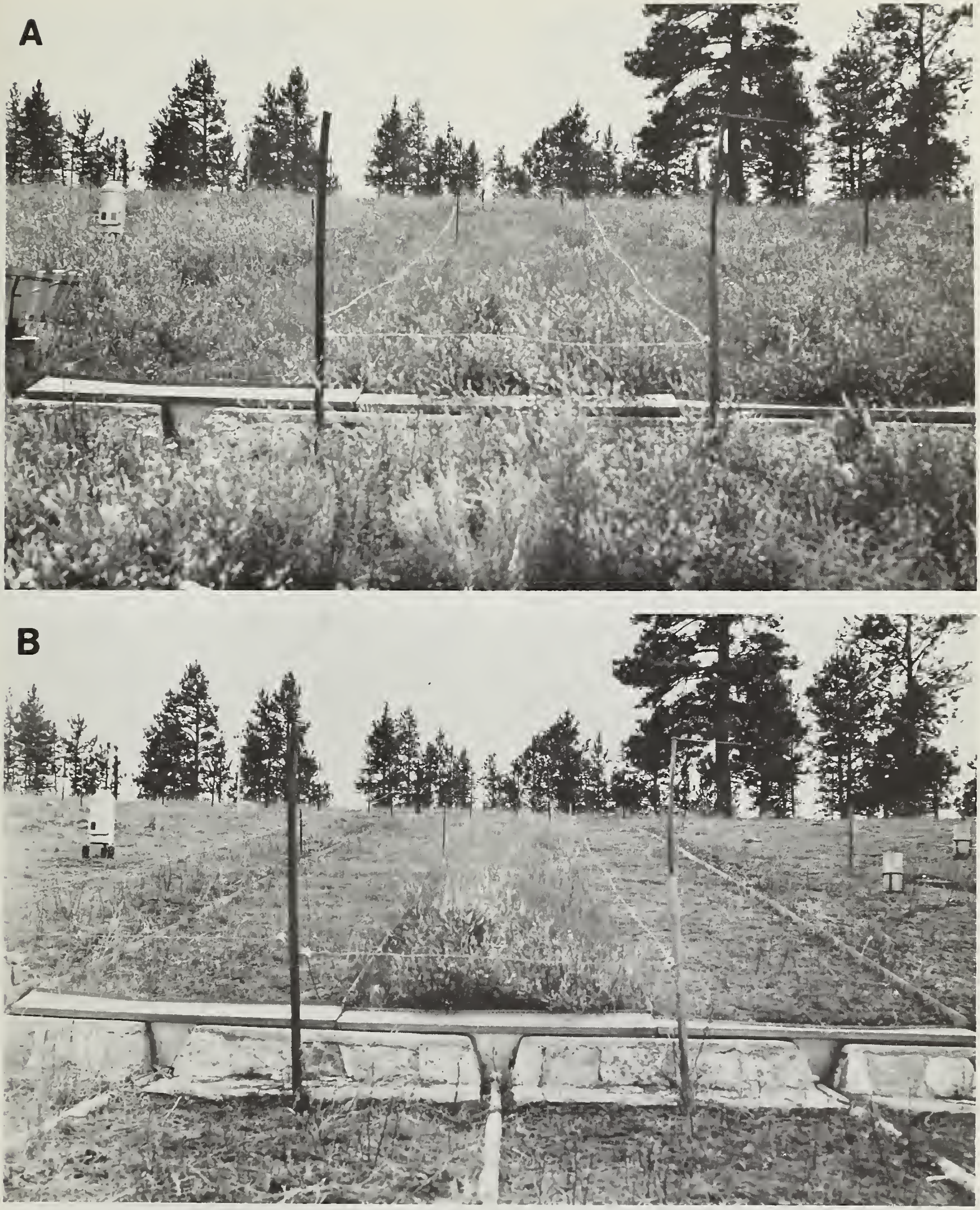

Figure 10.—Bunchgrass runoff plots: **A**, before grazing; **B**, after grazing by cattle (from left to right)—moderate, none, and heavy grazing.

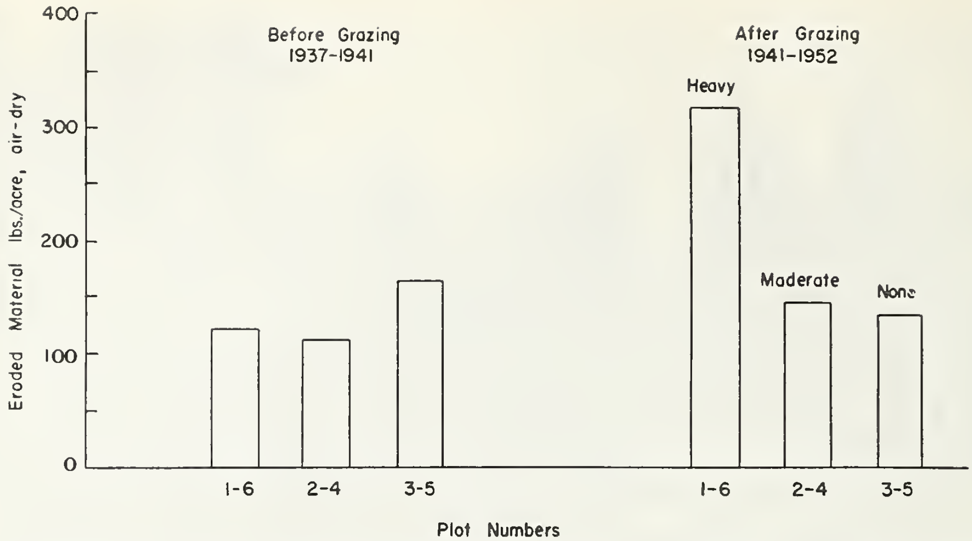

Figure 11.—Average erosion from summer rainfall, before and after grazing treatments (Dunford 1954).

in the ponderosa pine type, Dunford (1954) also found no erosion in the three summers of calibration, but did observe increases in erosion following litter removal in the first treatment, and after removal of trees as well as litter cover in the second treatment. In the first year after treatment, three plots in the treated block yielded an average of about 4 tons of air-dry eroded material per acre, while the untreated block yielded only a trace. After 5 years, the amount of air-dry eroded material derived from the treated plots (0.01 acre) decreased from 25.4 to 1.0 pounds per storm. No erosion occurred from 1946 through 1952, and it was concluded that the effect of litter removal in 1941 had been virtually eliminated by the gradual return of a ground cover. In the second treatment on the same plots, removal of trees and litter again resulted in seasonal average erosion in excess of 4 tons per acre, while the undisturbed plots produced none. These two treatments showed the protection afforded by forests in the Front Range watersheds, and suggested the use of forest management systems causing the least ground disturbance.

A forage condition survey by Reid and Love (1951) on the Elk Ridge Allotments showed that 96 percent of the usable range types were in depleted condition from the standpoint of the desired amount of forage. The grassland and meadow, brush, timber-grass, and aspen types were predominately in fair condition, but substantial portions of each were also in poor condition. From infiltration plot data, Reid and Love were able to develop a relation between erosion rate and live material plus litter on a schist-derived soil (fig. 12). Erosion rate was directly related to the amount of vegetation and litter. Where vegetation and litter are sparse, any increase in either or both would have a major effect in reducing erosion. The effect would be proportionately greater where amounts of vegetation and litter are relatively small.For the grassland and timber-grass types on granite-schist soils and on slopes less than 40 percent, Reid and Love (1951) considered that satisfactory watershed cover for protection against a 2.5-inch storm (30-year storm) would be: (1) on

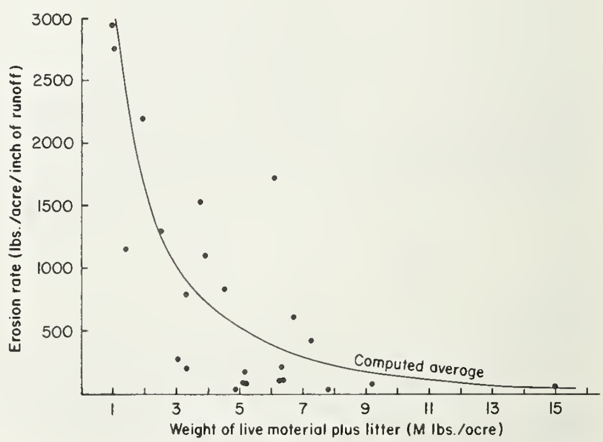

Figure 12.—Relations between erosion rate and live material plus litter on the grassland type on schist-derived soils (Reid and Love 1951).

grassland type, 1,100 to 1,300 pounds per acre of herbage; and (2) on timber-grass type, 17,000 to 21,000 pounds per acre of litter. From past storm records, infiltration, and erosion rates, they were able to estimate reductions in anticipated peak flows and erosion that would result from putting all grassland and meadow types and half the timber-grass types in good condition as a result of range management practices (table 2).

Table 2.--Expected runoff and erosion reduction on four areas placed under good range condition class on Elk Ridge Allotments (Reid and Love 1951)

Area	1-inch storm	2-inch storm	2.5-inch storm
		Percent	
REDUCTION OF PEAK FLOWS:			
North Fork	75	26	13
Hell Canyon	35	11	6
North Fork, Little Thompson	50	11	5
Grassland (schist-derived soils)	0	0	0
REDUCTION IN EROSION:			
North Fork	69	32	31
Hell Canyon	40	19	21
North Fork, Little Thompson	53	24	27
Grassland (schist-derived soils)	0	60	60

In the same report, Reid and Love (1951) also found that general grassland and meadow types produced the least sheet erosion in proportion to the area of the types. Ninety-five percent of the areas with moderate sheet erosion were on the timber-grass and browse types.

Evaluation of Rainfall Infiltration and Erosion Studies

Much of the early concern for the protection of pine-bunchgrass rangelands originated from infiltrometer studies in which artificial rainfall was used to simulate short-duration summer thunderstorms. Precipitation was applied at a rate of 4 to 5 inches per hour for a 50-minute period (Dortignac 1951). These rates far exceeded normally observed rainfall intensities in the area.[3]

[3]*According to Love (1958), maximum 10-minute intensities average 3 to 3.5 inches/hr for summer cloudburst storms. Such storms produce a total precipitation of 2.5 to 3 inches, last approximately an hr, and have a recurrence interval of 50 yr.*

While these studies have shown that good range management practices and revegetation of depleted land with trees, shrubs, and grass will improve watershed conditions, such measures cannot offer complete protection against damage from infrequent severe floods. It must be recognized that improved range and forest management practices are essential to avoid triggering and intensifying destructive geologic effects. However, no watershed management practice in itself can prevent normal geologic processes which are characteristic of the Front Range.

Channel Erosion

Throughout much of the Front Range pine zone, meadows and hillsides are typically lined with gullies (fig. 13). Accordingly, mechanical structures and treatments have long been used and are still needed in some areas to control runoff and soil erosion. Heede (1960) evaluated the gully-control structures installed some 30 to 35 years ago in the Pike and San Isabel National Forests, and made recommendations to guide future work in gully control.

Many gully-control structures have apparently failed because of poor engineering and because maintenance work is seldom performed. The main damage probably occurs during the infrequent storms that produce large floods.

Adequate field guides and engineering designs for gully control have long been available (Heede 1966).[4] In 1965, Heede designed a check

[4]*Rosa, J. Martin. 1954. Guides for program development: Flood prevention on small watersheds of the Rocky Mountain area. U.S. Dep. Agric., For. Serv., Ogden, Utah.*

Figure 13.—Erosion channel through a heavily grazed meadow.

dam system based on prefabricated concrete components to simplify construction of check dams in relatively remote areas (fig. 14). The best methods of plant establishment and kinds of plants to complement control structures are not fully known, however (Heede 1968).

Studies of channel morphology (Heede 1970) led to the development of computerized procedures for designing an engineered series of control structures for the entire length of a gully system (Heede and Mufich 1973, 1974).

In Heede's (1967) 7-year study of gully fusion on the Manitou Experimental Forest, only five summer storms produced gully flows. He also observed that gully flows were not recorded during spring snowmelt, and he believed that the usually limited snowpack and rate of melt were not sufficient to cause concentrated gully flow and the upstream progression of gully head cuts.

Heede's work and the flood events of recent years indicate that some gully activity is caused by short-duration summer cloudbursts; however, the most severe erosion takes place during large-scale moderate-intensity upslope storms. Such storms can be associated with snowmelt runoff from the higher elevations in May and June. Hansen (1973) reported that "in terms of geologic effects such as scour and especially mass wastage, the (May 5-6, 1973) storm was unusual—probably because of the thorough saturation of the ground that resulted from the moderate rate of sustained precipitation." In this particular storm, "nearly all perennial streams in the area, and countless intermittent ones,scoured segments of their banks and beds" (Hansen 1973). Several examples of severe scour by Front Range streams are cited by Hansen (1973). Of particular significance was West Creek between Deckers and Woodland Park, in which "two small reservoirs failed in sequence, the upstream one first, by overtopping, thereby swamping the lower dam and creating a 'wall' of water that destroyed much of the highway and several mountain homes."

Hansen (1973) also documented considera-

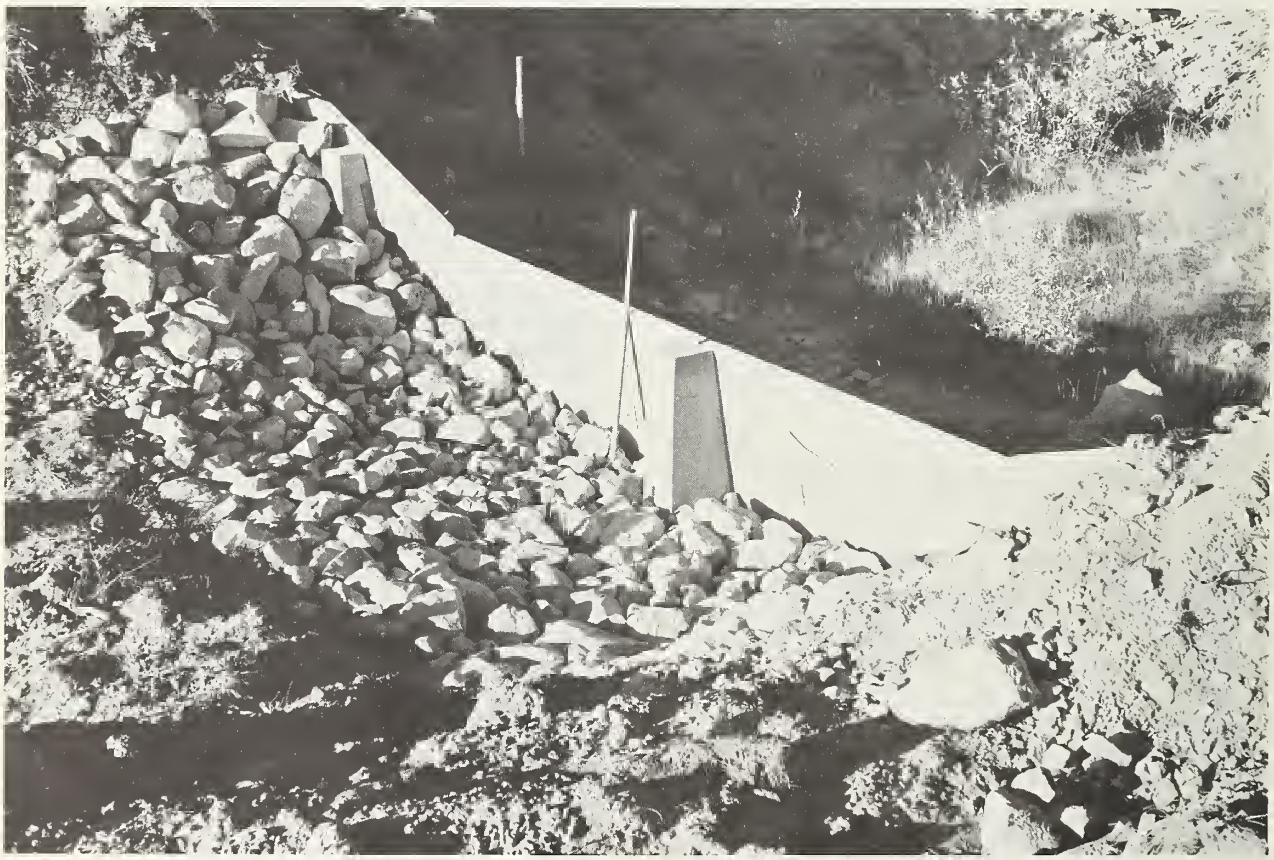

Figure 14.—Downstream face of completed prefabricated concrete check dam (Heede 1965).

ble mass wastage in saturated slide-prone areas. He noted that slumps and earthflows were most prevalent in foothill areas, underlain by sedimentary rocks; however, landslides and rockfalls also occurred higher in the mountains. Many of the slumps disintegrated into mud and earthflows that ran out onto roadways and into water courses.

Sediment Yield

Upstream channel erosion contributes sedimentation damage to downstream improvements. On the Manitou Experimental Forest it has been estimated that gully erosion accounts for 60 percent of the sediment in stream channels and reservoirs. Thus, reservoir sedimentation in the Front Range can be a significant problem. Within the Manitou Experimental Forest, there is a good example of the magnitude of sedimentation in a small reservoir (USDA FS 1949). The dam for Manitou Lake was completed in 1937. Original capacity of the reservoir was 93 acre-ft. By 1948, the capacity had been reduced by two-thirds, and approximately 60 acre-ft of sediment had accumulated below the spillway level. Total accumulation above and below the spillway level was about 200 acre-ft, with channel deposits as much as a mile upstream. Rate of sedimentation in this case is typical of many Front Range streams. The drainage basin above the reservoir is 69 mi^2. Based on estimates of total accumulation, the contribution from the drainage area is 18.2 acre-ft per year, or 0.26 acre-ft/mi^2 annually. Most of the sediment was probably deposited by infrequent flood events.

Watershed Protection Criteria

Forest and Range Management

A survey of about 30 timber sales and old cutover areas on the Roosevelt and Pike National Forests gave some indications of the need for watershed condition criteria (USDA FS 1944). It was found that even the most severe timber cutting in the spruce-fir and lodgepole pine types had few bad effects on watershed conditions. Some damage has been caused by repeated perennial use of skid roads and trails, and by poor planning of logging roads (fig. 15).

Figure 15.—A poorly planned skid trail established in the 1920's in the Front Range spruce-fir type. Elevation about 10,000 ft.

In general, however, cutover areas in these types are now in a stable condition, and most logged areas are well covered with vegetation.

In the same survey, it was observed that logging in the ponderosa pine and Douglas-fir types may be hazardous, compared to spruce-fir and lodgepole pine types. Watershed conditions and the effects of logging in these types vary greatly with environmental factors such as soil, topography, and exposure. In these types, practically no logging damage was observed on slopes under 10 percent. Logging in Douglas-fir areas had done little damage except through erosion from poorly planned logging roads. The selective logging in Douglas-fir areas has usually left an ample stand of trees and an understory of shrubs and herbs.

The most serious erosion problem in the ponderosa pine type was found on slopes steeper than 30 percent and on unstable soils such as those derived from Pikes Peak granite and volcanic rocks. Problems are greatest on warm and dry slopes, where erosion would result from timber cutting even without damage from skid roads or trails. Progressive deterioration of such sites after removal of trees is often aggravated by grazing damage, and may culminate in complete exposure of the soil with subsequent surface runoff.

Results from the survey above indicate that improved logging methods along with vegetation of denuded areas to either grass or trees will prevent depletion of the range and watershed values of the Front Range pine zone. Efficient means of recognizing and controlling active gullies, and sheet and streambank erosion are generally known, but the necessary controls have not been applied. Grading, mechanical structures, and the right combinations of vegetation should be applied to build up channel storage in many headwater streams. On less hazardous areas, such as the gently sloping valleys, controlled grazing can be allowed.

The extremely deteriorated areas need some direct improvement in addition to protection because natural return of vegetation is slow. Johnson (1945) believed the degree of grazing pressure in the Front Range was equally as important as erosion and runoff in its effect on plant succession and site restoration. Overgrazing may maintain an intermediate and undesirable stage of plant succession and poor ground cover indefinitely. Successful seeding of some depleted farm and grazing lands has resulted in herbage yields three to five times that of adjoining native range, and at the same time has provided adequate ground cover (Johnson 1959).

Onsite flood damage is usually at a minimum in the Front Range when native plants—grass, browse, trees—are produced at a maximum rate. Using infiltrometer tests, corroborated by plot runoff data, Dortignac and Love (1960) and Reid and Love (1951) have provided some basis for determining satisfactory watershed criteria. For soils derived from granite and schist on slopes up to 40 percent, organic materials should exceed 2 tons per acre, or 1,000 to 1,300 pounds of live herbage per acre (fig. 16). If any area on a 40 percent slope is capable of producing only 1,200 pounds of live herbage without being grazed, then it must be protected from grazing to meet satisfactory watershed criteria. Areas of lesser slope usually produce more than adequate herbage for watershed protection, and may be grazed to the extent that the herbage produced exceeds the guide figure; otherwise, increased surface

Figure 16.—Under good litter or grass cover, infiltration rates are usually sufficiently high to restrict surface runoff and erosion in the timber-grass types.

runoff and erosion may be harmful to the continued productiveness of the site.

In the timber-grass types on soils derived from a mixture of granite and schist, trees occur in open stands and the understory is usually native bunchgrasses, which are often sparse. Quantity of litter appears to be a major hydrologic factor. On these areas, much of the litter is pine needles, cones, and small twigs. The grasses in the timber type contribute limited amounts of litter. It has been estimated that 19,000 to 21,000 pounds of litter per acre should be maintained on the timber-grass types (Reid and Love 1951). Tree removal should be avoided on areas with lesser amounts of litter and where shallow soils dominate. Areas with greater soil depth may be logged or grazed to the extent that the remaining soil protection does not fall below the guidelines.

Urbanization

Rapid urbanization of the Front Range is intensifying watershed protection problems. Of primary concern to planners are the hazards created by common land development practices with respect to road construction, drainage, steepness of natural slopes, building site location, and a host of related factors. Hansen (1973) has documented an excellent summary of many of these practices which tend to trigger geologic processes, thus compounding the intensity and damage from extreme flood events. Better land use planning is essential if future problems are to be minimized.

Present Water Yields

The classic Wagon Wheel Gap study provides some of the earliest detailed information and guidelines as to water yields that may be expected from the 9,300- to 11,300-ft elevational range along the east slope of the southern portion of the Colorado Rockies (Bates and Henry 1928). Water yield in that study averaged about 6 inches, and similar water yields may be expected under forest cover and in logged areas near the extreme upper limits of the ponderosa pine zone in other parts of the Front Range. The forest cover in their study area was mainly Douglas-fir and aspen, and precipitation averaged about 21 inches. On the average, about 29 percent of the precipitation was yielded as runoff. Runoff ranged from 42 percent of the precipitation during years of above-average snowfall to 17 percent during low snowfall years (fig. 17).

Annual water yields in the Front Range pine

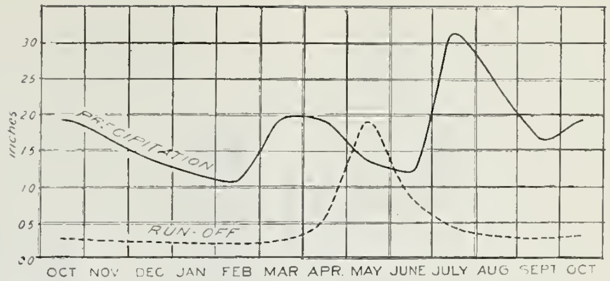

Figure 17.—Average monthly distribution of precipitation and runoff from a Wagon Wheel Gap, Colorado, watershed (Bates and Henry 1928).

type range between 3 and 5 inches, or about 10 to 15 percent of the annual precipitation. The greatest opportunity for runoff is probably from April through August (see fig. 3). Infrequent large storms of moderate intensity in May and June are the major source of damaging flood flows.

In the mid-elevations of the pine zone, plot studies have provided some runoff guides for land managers. In one such study, Dunford (1954) summarized the runoff from grass plots over a 16-year study period at Manitou, and found that individual summer storms produced measurable runoff four or five times per year from untreated plots; amount varied with vegetation cover. Average surface runoff was about 0.25 inch for 4 years before the grazing treatments. During 12 years of treatments, the heavily grazed plots yielded an average of 0.34 inch of runoff per season, moderately grazed 0.22 inch, and nongrazed 0.11 inch per season (fig. 18).

Reid and Love (1951) summarized streamflow and the timing of runoff for the North Fork of the Little Thompson watershed on the Elk Ridge Allotments and for the Missouri Gulch watershed at Manitou for the years 1949 and 1950. Inches of runoff for years of high and low water yield were as follows:

	1949	**1950**
	(Inches)	
North Fork,		
Little Thompson	3.78	0.69
Missouri Gulch	2.11	.58

In both years, streamflows on the North Fork watershed peaked in June. In 1949, about 80 percent of the total annual flow on North Fork occurred during the month of June as a result of prolonged rain-on-snow events. The period of greatest seasonal runoff was much the same for

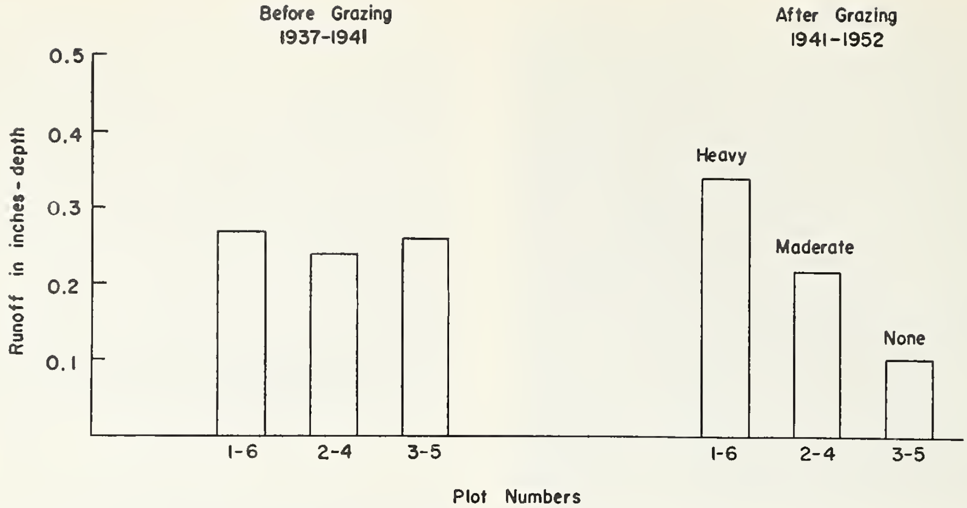

Figure 18.—Average seasonal runoff from summer storms before and after grazing treatment (Dunford 1954).

Missouri Gulch in 1949; more than half of the annual flow occurred during May, June, and July. In 1950, under low precipitation, more than 50 percent of the flow from both watersheds also occurred in May, June, and July.

Precipitation over the Missouri Gulch watershed is characteristic of that over much of the Front Range. Precipitation usually comes as snow from late September through May. Snow commonly melts on south exposures and valleys within a few days, and accumulates during the winter mainly on north exposures. Snowmelt from the lower end of the watershed (elevations below 8,300 ft) has the greatest influence on the spring peaks, which account for about 40 percent of the total annual yield. Yearly streamflow has varied from 8.14 inches in 1942 to 0.25 inch in 1956. Average annual streamflow for the 19 years of study was 2.22 inches. These runoff values are generally characteristic of Front Range drainages on granitic formations. Water yielded as streamflow from the Missouri Gulch watershed averages between 10 and 15 percent of the total annual precipitation. In contrast, the high-altitude watersheds of the Continental Divide yield about 50 percent of the precipitation (USDA FS 1948, Leaf 1975). Monthly mean precipitation and streamflow for the 19-year period on the Missouri Gulch watershed (fig. 19) are similar to those previously shown (fig. 17) for Wagon Wheel Gap.

On the Missouri Gulch watershed, Berndt (1960) reported that in 12 of 18 years, the maximum storm peak was recorded in May within 3 weeks after the instantaneous spring peak was reached. The May peak flows were the result of rain or very wet snow at a time when the watershed was still charged with snowmelt water. The occurrence of an instantaneous hydrograph peak some 30 minutes after the peak of the storm is characteristic (fig. 20). Summary thunderstorms of high intensity and relative short duration are responsible for the sudden rise and fall in streamflow. The peak intensities appear to be related to the size of the storm, and are responsible for surface runoff and erosion. At the Manitou Experimental Forest, it has been found that summer thunderstorms averaging greater than 0.96 inch will cause surface runoff and erosion (USDA FS 1949).

The frequency of thunderstorms and the antecedent storage in the soil mantle also affect the percentage of rainfall that will be yielded as streamflow. During the wet summer of 1945 at Manitou, a series of five large storms occurred in slightly over 5 weeks, with several smaller storms interspersed between (USDA FS 1949). The rainfall, runoff, and percent yield from the Missouri Gulch watershed were as follows:

	Precipitation	**Storm runoff**	**Yield**
	(Inches)		*(Percent)*
July 14	0.66	0.004	0.61
18	.56	.002	.36
31	.73	.013	1.78
Aug. 13	.65	.081	12.46
30	1.94	.540	27.84

The higher yields during August indicated high soil moisture and little opportunity for the storage of additional rainfall. The above conditions

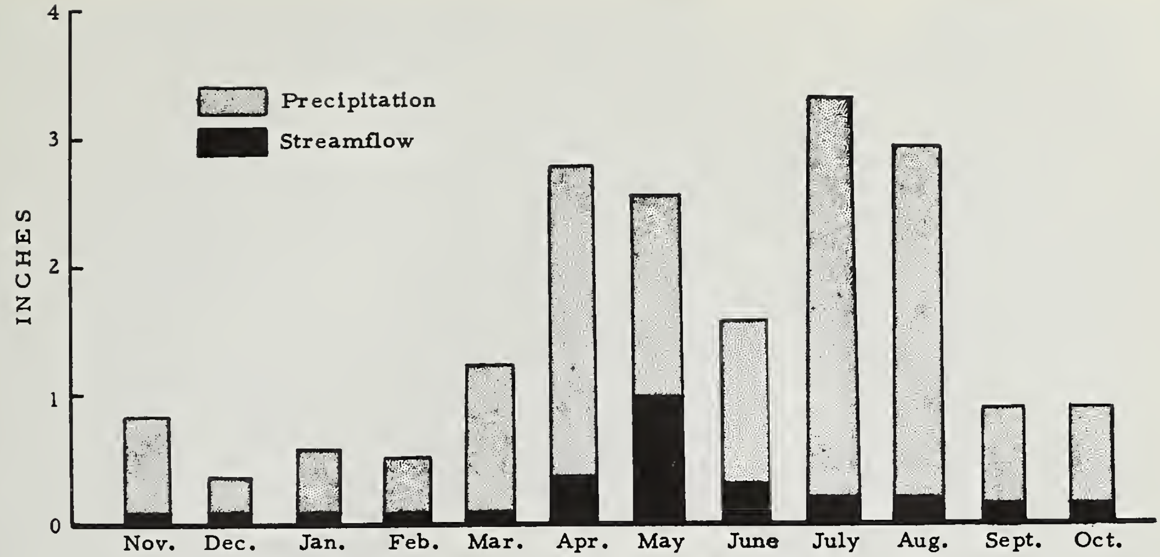

Figure 19.—Monthly mean precipitation and stream flow, Missouri Gulch watershed, Manitou Experimental Forest, 1940-58 (Berndt 1960).

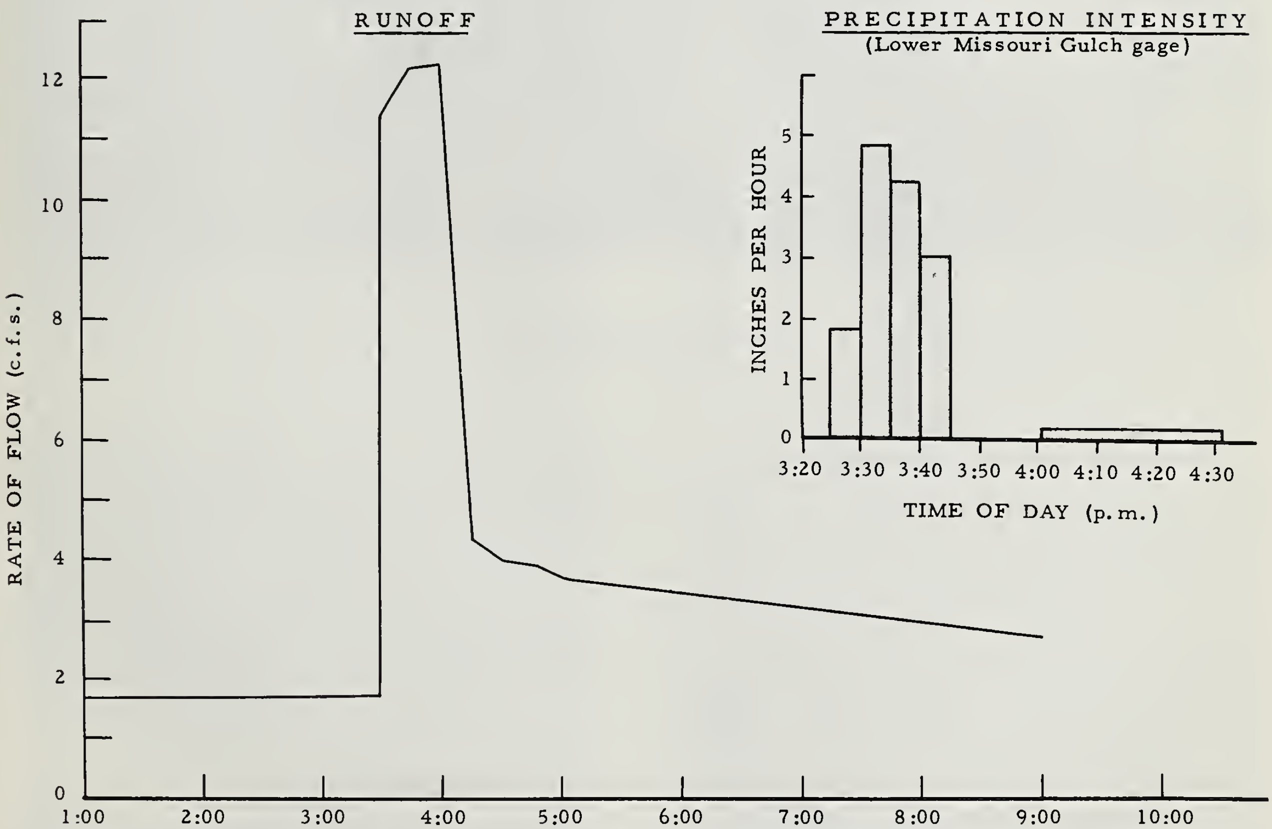

Figure 20.—Hydrograph resulting from the storm of July 29, 1947 on the Missouri Gulch watershed on the Manitou Experimental Forest (Berndt 1960).

are analogous to those in spring: low recharge requirements, a melting snowpack, and spring rains, which in some years can produce dangerous flooding. An analysis of 25 summer storms showed that volume of precipitation and antecedent flow accounted for 80 percent of the variability in storm runoff. Precipitation alone accounted for not more than 50 percent of the variability.

Improvement of Water Yields

There is adequate research evidence that water yields can be increased in the high-elevation subalpine forests in the Colorado Rockies after removing forest cover (Bates and Henry 1928, Goodell 1958, Leaf 1975).

Hoover (1959) believed that "much more is involved than simply cutting all of the trees or some percent of the stand. Too much attention has been given to the vegetation cut and too little attention paid to what vegetation should remain. The real need is to spell out what kind, size, age, and arrangement of plant cover is the most effective for specific situations." Similar views were held by Croft (1961). Some opportunities for increasing water yields in the Front Range are discussed in the following sections.

Snow Management

In the Colorado Front Range, the seasonal snowpacks develop mainly at elevations above 9,000 ft; few snow courses have thus been established to measure the shallow snowpacks in the pine zone below that elevation. Of some 30 snow courses on the South Platte River drainage, apparently only one is located in the ponderosa pine type, at an elevation of 7,900 ft. Three other snow courses are located between 8,600 and 8,800 ft, and the rest are at elevations above 9,000 ft (Washichek and McAndrew 1967).

Forest management in the ponderosa pine zone offers possibilities to change the pattern of snow accumulation and increase water yield. Love (1960) and Berndt (1961) pursued the possibility in a 2-year study of a National Forest timber sale near the Manitou Experimental Forest. In a mixed stand of ponderosa pine and Douglas-fir on a north exposure at 8,500 ft, the water equivalent of overwinter snow accumulation was measured under cut and uncut stands. Before harvest, the stand of merchantable timber (trees over 10 inches d.b.h.) had an average volume of 10,000 bd ft (fbm) per acre. Total basal area averaged about 120 ft^2 per acre. Two plots were left uncut, while 60 percent of the merchantable volume was selectively cut on two others. Basal area was reduced to 94 ft^2 per acre under selection cutting and to 43 ft^2 under commercial clearcutting.

Snowfall during the two winters studied was different, but the increase in water equivalent on the commercially clearcut plots ranged from 8 to 35 percent and was statistically significant when compared to the uncut plots. Snow cover over the selectively cut and uncut plots was similar. Snow disappeared from all plots at about the same time, indicating a speedup in snowmelt on the commercially clearcut plots. No provision was made to determine whether the increased water equivalent of the snowpack affected streamflow. Implications were that water yield might be increased from north exposures by commercially clearcutting mature stands of ponderosa pine and Douglas-fir.

Studies in the higher snowfall zones near the Continental Divide have indicated that increased runoff and higher spring freshets would be expected after patchcutting, which changes the usual snow distribution pattern by increasing snow accumulation in cleared areas and reduces evapotranspiration (Leaf 1975). The same principles apply to protected sites in the Front Range pine zone (fig. 21). Low evapotranspiration demands during the early spring period favor higher water yields from melting snows. The Wagon Wheel Gap study (Bates and Henry 1928) showed that about 50 percent of the annual precipitation came as snow, but water yield from the melting snows between March 30 and June 30 accounted for about 55 percent of the annual runoff. On the average, snowpack near Wagon Wheel Gap melted by March 25 on the south aspects and by May 15 on the north aspects. In the lower elevation Front Range ponderosa pine zone, the shallower snowpacks on similar slopes would probably melt prior to those dates.

For specific areas where water has extremely high value, it may be possible to increase the potential for water yield from the limited snow resource by applying evaporation suppressants, which slow or stop the movement of water vapor from the snow surface to the air. By applying monolayers of long-chain fatty alcohols such as hexadecanol to the snow surface in the central Sierra Nevada, Anderson and others (1963) found that evaporation reduction ranged from 35 percent under dense forest cover to 88 percent in large open meadows.

Forest Management

Reducing evapotranspiration and changing the patterns of snow accumulation by vegetal manipulation probably holds more potential for

Figure 21.—Late-lying snow in a small rectangular clearing on a north-facing slope on the Manitou Experimental Forest.

increasing streamflow than any other feasible means. Such increases in streamflow in the ponderosa pine zone will most likely come from drainages such as the Missouri Gulch watershed. This watershed, with its highly variable vegetation types and physiography, appears characteristic of much of the pine type. Average water yield is about 2.22 inches from an average annual precipitation of about 18.22 inches (Berndt 1960).

Management of selected riparian and other wet sites supporting trees or willows (*Salix* spp.) also offers considerable potential for increasing water supplies (Horton and Campbell 1974). It is worth noting that water rights resulting from such practices have already been adjudicated in the Front Range pine type and in the Arkansas River drainage basin near Swink, Colorado (Mountain Business Publishing, Inc. 1974). Type conversion from aspen-grass to only grasses and herbaceous plants in one Utah study resulted in an annual soil-moisture savings of about 3 inches (Croft 1950).

Clearcutting in about 80-year-old Front Range lodgepole pine, near Pingree Park, has shown a considerable savings of soil moisture. Dietrich and Meiman (1974) studied soil-moisture storage in the upper 6 ft of soil before cutting patches about 0.5 acre in size on slopes ranging from 20 to 30 percent at 9,000 ft elevation (table 3). From this and similar studies, it is presumed that less water will be required for

Table 3.--Summary of soil-moisture storage in the upper 6 ft of soil before and after small patchcuts in Front Range lodgepole pine, by aspect (Dietrich and Meiman 1974)

Aspect, treatment, and date	Treated area	Control area
	Inches of water	
South 86° East:		
Before patchcut, Sept. 1970	12.4	12.1
After patchcut, Sept. 1972	13.7	8.2
North 40° East:		
Before patchcut, Sept. 1970	12.7	12.1
After patchcut, Sept. 1972	14.3	7.8
North 33° West:		
Before patchcut, Sept. 1970	8.9	8.5
After patchcut, Sept. 1972	10.9	5.2

soil-moisture recharge, and any additional amounts of rain or snowmelt after recharge will be yielded as streamflow.

In Orr's (1968) study of a second-growth ponderosa pine stand in the Black Hills, thinning from 190 ft^2 of basal area and about 2,000 trees per acre to 80 ft^2 and 435 trees did not induce free water seepage to ground water in dry years. On his clearcut plot, free water seepage did occur even in dry years. The establishment of Kentucky bluegrass over the cleared plot subsequently reduced seepage yield potential, but the potential remained higher than in thinned and unthinned portions of the stand because of less capacity for moisture depletion from the entire soil mantle.

A root study of some native trees and understory plants on the Manitou Experimental Forest generally supports Orr's (1968) conclusions. Berndt and Gibbons (1958) observed that, in general, roots of ponderosa pine, Douglas-fir, lodgepole pine, and true mountainmahogany (*Cercocarpus montanus*) reached maximum depths between 4 and 5.6 ft, except where limited by bedrock. For mountain muhly (*Muhlenbergia montana*), Arizona fescue (*Festuca arizonica*), and kinnikinnick (*Arctostaphylos uva-ursi*), they noted that maximum rooting depths were between 2 and 3.4 ft.

Selective cuttings within forests have generally shown lesser soil-moisture savings and small or negligible increases in streamflow (Leaf 1975). In a 30-inch rainfall and 3-inch streamflow region in the ponderosa pine, Douglas-fir, white fir (*Abies concolor*) type (Workman Creek) in central Arizona, Rich (1965) found that a commercial timber harvest on an individual-tree selection basis, which removed 46 percent of the basal area of trees on the watershed, did not significantly increase streamflow. Water demands by the residual stand of trees evidently used most of the additional water made available by timber harvesting. In the same study, clearcutting 80 acres of moist-site forest vegetation increased streamflow about 46 percent. Rich concluded that clearcut openings and a change to even-aged timber management may be possible ways of maintaining the timber supply as well as increasing water yields.

The necessity of some form of clearcutting to increase water yields was again observed by Rich (1972) in eastern Arizona. He reported that clearcutting about one-sixth of the timber (mainly ponderosa pine) on the 900-acre West Fork Castle Creek watershed—roughly half of the proportion clearcut on the Workman Creek watershed—increased runoff 29 percent—slightly over half that computed for Workman Creek. Similar increases in runoff were observed from various patterns of clearcutting on Beaver Creek in central Arizona (Brown and others 1974).

In the subalpine zone of Colorado, where annual precipitation averages 30 inches, Leaf (1975) reported total water yield increases of more than 25 percent after strip cutting about 50 percent of the merchantable pine-spruce-fir timber on the Fool Creek watershed. After clearcutting the sparsely stocked stand of Engelmann spruce, Douglas-fir, and aspen on a watershed near Wagon Wheel Gap, Colorado, where precipitation averaged about 21 inches, Bates and Henry (1928) observed a 17 percent increase in streamflow.

Rangeland Management

Forage values have been damaged to some extent by excessive grazing or previous cultivation of productive rangeland in some areas of the ponderosa pine zone of Colorado (Hull and Johnson 1955). On such lands, it has long been recognized that runoff and erosion are closely related to the abundance of desirable bunchgrass, amount of litter on the soil surface, amount of bare soil, and infiltration capacity. Grazing use today is about half the estimated 300,000 head of cattle on the Front Range in 1950, but there remains a need to use improved methods of grazing management on native and reseeded pastures (Smith 1967, Currie and Smith 1970) to provide satisfactory watershed conditions (fig. 22). Other land use practices on the grazing lands, such as road building and urban development, must also be better planned to meet overall watershed objectives.

Figure 22.—Better grazing management on overgrazed rangelands (**A**), and revegetation on abandoned farmlands and completely deteriorated rangelands (**B**) will provide soil-protecting cover to minimize runoff and erosion.

Love (1958) pointed out that "forage production and water yield form a natural unit and reflect the interactions of soils, geology, climate, and vegetation by providing a common end product—runoff or streamflow—that can be measured and appraised." The rangelands in the Front Range pine zone are a mixture of forest, meadows, and abandoned croplands. On the Manitou Experimental Forest, for example, the pine ranges were divided into four classes: (1) grassland parks, untimbered; (2) open timber, ponderosa pine; (3) stands of dense timber with dense canopies; and (4) fields once cultivated, but now abandoned (Johnson 1953). Forage production is widely variable, and along with the diversity of the rangelands, complicates most rangeland watershed management programs.

From infiltration studies on the Front Range, it has been concluded that a good plant cover on coarse and porous soils minimizes surface runoff and erosion. In the grassland types, good plant cover generally indicates good range condition and potential for forage production. In a survey of range-watershed conditions on a Front Range grazing allotment, Reid and Love (1951) scored forage conditions on the basis of ecological development of the range vegetation. They then measured infiltration under four conditions of range forage growing on soils derived from a mixture of granite and schist (table 4). The infiltration rate of the plots in good forage condition was 118 percent greater than plots in very poor condition. The erosion rate on plots in good condition was about one-fourth that from the plots in very poor condition. Studies in different soil types showed similar results—the good condition class provided the best watershed condition.

Table 4.--Infiltration, erosion, and related factors of range condition on a Front Range grassland (Reid and Love 1951)

Factor	Forage condition class			
	Good	Fair	Poor	Very poor
Herbage production *(Pounds per acre)*	1,230	944	709	925
Infiltration rate *(Inches per hour)*	2.22	1.64	1.23	1.02
Runoff *(Inches per 50 minutes)*	2.45	2.72	3.05	3.58
Erosion *(Pounds per acre per inch of surface runoff)*	166	269	699	528
Bare area *(Percent)*	4.7	12.0	20.1	20.8

After studying the effects of livestock grazing on surface runoff and erosion, Dunford (1954) made recommendations as to the limits for intensity of grazing use of the bunchgrass type on Front Range watersheds. He believed heavy grazing (2.5 acres per cow-month) went beyond the limits allowable in good watershed management. Erosion under that intensity of grazing began to accelerate above a rate which he regarded as normal. He found that erosion did not appear substantially increased as a result of moderate grazing (4 acres per cow-month) in spite of some additions to surface flow. In practice, he believed that moderate grazing on relatively gentle slopes was permissible if the increased runoff from summer storms did not cause critical shortages of moisture for plant development. His observations were partially substantiated by a large-scale pasture study of three intensities of grazing —light, moderate, and heavy (Johnson 1953). Moderate grazing has proven to be the most efficient from the standpoint of economic returns in production. The moderately grazed pastures were also reported as maintaining good annual forage production, plant vigor, and density. In a later report on the same pastures, Smith (1967) reached similar conclusions and recommended a grazing intensity that would utilize 30 to 40 percent of the dominant bunchgrass herbage by the end of the grazing season on ponderosa pine-bunchgrass ranges.

The infiltration studies, runoff plot studies, grazing studies, watershed studies, and surveys on the Front Range have generally shown the advantages of careful use of the forage and forest resources.

The degree to which vegetation can lessen the impact of floods and hold the soil in place is important to wise use of the Front Range ponderosa pine zone. Love (1958) believed the water yield can be increased by managing vegetation on grazed lands, if two conditions are met. He believed the first conditions should be an adequate soil cover and highly permeable soil, so that maximum amounts of water will enter the soil. His second condition was that the cover be composed of shallow-rooted plants or other plants that do not make large demands upon soil moisture.

Love's second condition for water-yield improvement may be only partially compatible with the most desirable level of range management. A study of root depths and lateral spread for several native plants under three intensities of grazing use on a typical ponderosa pine-bunchgrass range revealed that heavy grazing reduced grass root mass and penetration (Schuster 1964). In general, the reductions in root mass were proportional to the amount of

use on the individual grasses. Greater rooting depth under moderately grazed range appeared to indicate greater potential for soil-moisture withdrawal and less chance for increasing water yield than on heavily grazed range.

It is worth noting that a watershed experiment in Beaver Creek in central Arizona resulted in only an 8 percent increase in runoff due to 60 percent grazing use (Brown and others 1974). However, the authors point out that the increase "was not statistically significant at the 5 percent level and is not approaching practical importance." Negligible plant growth was observed, and soil compaction was apparently not sufficient to increase surface runoff.

The Role of Watershed Management in Land Use Planning

Watershed management technology has advanced to a level that warrants its consideration in comprehensive land use planning. Research has shown that carefully designed watershed management practices can provide practical solutions to many water problems resulting from development and urbanization along the Front Range (fig. 23). Although such solutions may be of a small scale, compared to the regional needs, they can be ecologically sound and feasible alternatives for maintaining water quality and augmenting municipal and domestic water supplies. In this connection, Storey (1960) observed that "even a small increase may mean an appreciable difference in total yield and would have great economic importance."

If watershed management has an important contribution to make, then land use planners will need to know how changes in the environment caused by timber harvesting will affect the water resource. The magnitude of any hydrologic change will depend on the pattern in which timber is harvested. Some logging methods can be detrimental to the water resource, whereas others can be beneficial. Therefore, the need for a planning tool which objectively evaluates the potential hydrologic

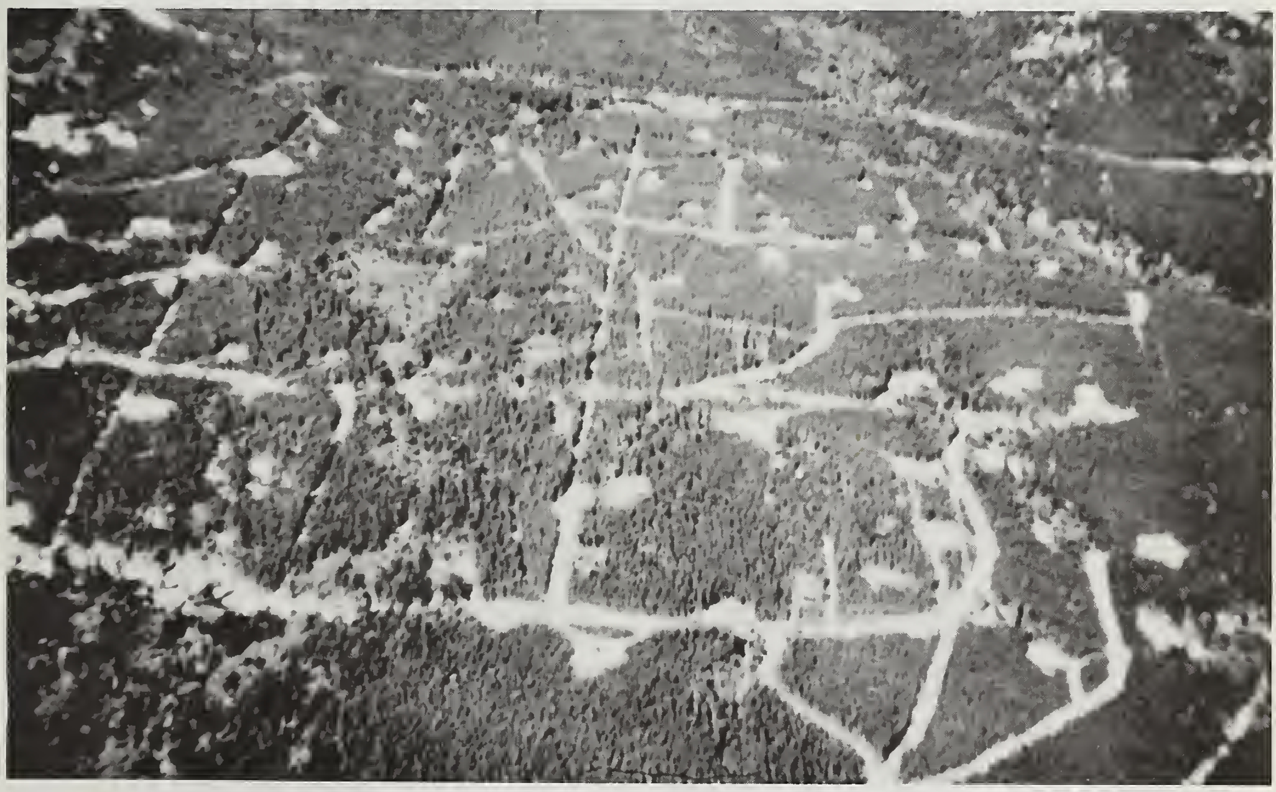

Figure 23.—Urbanization on private lands within the ponderosa pine belt along the Front Range. Inevitable development impacts on adjacent public lands are major challenges to land use planners.

effects of various timber harvesting strategies is obvious.

Progress has been made in the development of dynamic simulation models which predict the short-term effects of timber harvesting on snowmelt and water yield (Leaf 1975, Leaf and Alexander 1975). This work has been expanded to determine the long-term interactions between the water and timber resources with regard to partial cutting and regeneration practices in subalpine forests. The objective has been to design a model which: (1) is formulated in terms of the diverse form, structure, and arrangement of natural forest cover; and (2) at least qualitatively accounts for the response of these stands to management, based on the best information on hydrology and silviculture available.

These models are capable of simulating a broad array of timber harvesting alternatives; hydrologic changes can be determined for intervals of time which can vary from a few years to the rotation age of subalpine forests. The models have been calibrated for several representative drainage basins in the subalpine zone of Colorado and Wyoming.After additional calibration and testing to adapt them to the Front Range pine type, they should offer a relatively inexpensive means of providing improved information on potential hydrologic changes resulting from various forest and watershed management practices. Additional favorable aspects of these models are that they are no more complex than required to provide necessary information, and their application is not unduly restricted by data requirements. For the most part, data bases currently available in the Rocky Mountain region are adequate to begin operational testing of watershed management strategies in headwater streams.

Summary and Conclusions

The Colorado Front Range is generally regarded as the eastern foothills region of the central Rocky Mountain system. Land features consist of foothills, narrow mountain valleys, steep rocky canyons, large openings or parks, and mountain slopes and ridges. Most of the soils are derived from granites, are coarse textured, have relatively low productive capacity, and are potentially erosive once the protective covering is disturbed.

The area has a history of use going back more than 100 years, when the more accessible forests were cut over, and many ranges were heavily grazed by domestic livestock. The low-elevation (6,000 to 9,000 ft) forests and grasslands occur in various compositions. The major cover types include: (1) dense stands of pine with closed canopies and a ground cover of pine litter; (2) parks and other small openings consisting of herbaceous vegetation, mainly grass; (3) open pine stands with a ground cover of herbaceous vegetation; and (4) fields and valleys once cultivated. Stands of aspen are found scattered along valley bottoms, on benches, near the head of small drainages, and on old burns. Brush species grow at the lower elevations on south exposures and also on old burns. Mixed conifers (Douglas-fir, ponderosa pine, and Engelmann spruce) and lodgepole pine are common, but occur mostly on north exposures and on the more moist sites.

The climate in the Front Range pine type is highly variable. Most of the annual precipitation, which ranges from 15 to 20 inches, falls as rain during April through October. Precipitation amounts for selected stations range from about 10 inches to slightly more than 30 inches. Light afternoon showers are common from July through September. The average storm size required to cause runoff is about 0.96 inch. It is common for rainfall intensities to reach 3 inches per hour for 5-minute periods, but storms exceeding 4 inches per hour are rare. For the Front Range as a whole, three to five storms per year have sufficient intensity to produce surface runoff. Precipitation may be in the form of snow from late September through May, but snows commonly melt from the south exposures and valleys within a few days. The shallow snowpacks at the highest elevations and on the protected north exposures in the pine type generally disappear by the middle of May. Annual water yields in the Front Range pine type range from 3 to 5 inches, or about 10 to 15 percent of the annual precipitation.

The Front Range has had a long history of major flooding. Flooding can occur from high-intensity rainfall on small areas in the foothills. However, major floods are caused by large upslope storms in May and June which deposit large quantities of rainfall below 7,000 ft, and deep snow above this elevation. Such floods trigger small-scale geologic processes which, in combination with high water, pose a persistent treat to uncontrolled urbanization along the Front Range.

Infiltrometer studies have provided guidelines for maintaining satisfactory watershed conditions in the Front Range ponderosa pine type. In the grassland type, on-the-ground organic materials should exceed 2 tons per acre, and live herbage should exceed 1,300 pounds per acre. In the pine type, about 20,000 pounds of litter per acre should be maintained. Tree removal should be avoided on areas with shallow soil and less than 20,000 pounds of litter.

Figure 24.—A small clearcut patch in ponderosa pine after harvest by the seed-tree method. Small clearcut openings or drastically thinned forests are necessary to significantly increase water yields (Boldt and Van Deusen 1974).

Areas with greater soil depth require somewhat lesser amounts of litter to maintain satisfactory watershed conditions, and may be logged or grazed to the extent where the remaining litter accumulation does not fall below the guidelines.

In the Front Range pine type, as elsewhere, hydrologic studies have shown that clearcut openings are necessary to significantly increased water yields. Highest water yields apparently result when trees are harvested in small patches (fig. 24). When forest openings are: (1) less than five tree heights in diameter; (2) protected from wind; and (3) interspersed so that they are five to eight tree heights apart, an optimum pattern of snow accumulation results. More snow is deposited in the openings, and less snow accumulates in the uncut forest so that total snow storage is not significantly increased. The snow in the forest openings melts earlier in the spring, at a time when evaporation is lower. Moreover, in the absence of trees, consumptive use is decreased; thus more water is available for streamflow. The **pattern** in which trees are harvested determines whether or not runoff will be increased. When the forest cover is removed in large clearcut blocks or by selective cutting of individual trees, water yields will be increased far less than if the same volume of timber were harvested in a system of small, dispersed forest openings. Under some conditions, streamflow may actually be decreased when timber is selectively harvested or clearcut in large blocks.

Minimal water-yield increases can also be

expected on grazed lands under conditions of adequate soil cover and highly permeable soil, so that maximum amounts of water will enter the soil. Another requirement is that cover be composed of shallow-rooted plants that do not make large demands upon soil moisture. The second condition may not be compatible with desirable range management because high forage-producing plants on moderately grazed range have greater rooting depths and greater potential requirements for soil moisture.

Water yields are important in the Front Range pine zone. Although the 3- to 5-inch yields are comparatively small in contrast to yields of 12 to 25 inches of water from the high-altitude subalpine forests, watershed management practices can be expected to provide feasible solutions to many water-supply problems as competition for this limited resource increases. New problems, such as the chemical properties and bacteriological quality of water brought to the forefront by expanding foothills communities, all collectively show the need for careful land use planning and wise use of the forest and forage resources. The balance between the vegetation (timber and grass) that can be used and the amount sufficient for satisfactory watershed conditions is critical to management and preservation of the soil resource of the Front Range pine zone.

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Guidelines are provided for maintaining satisfactory watershed conditions. The 3- to 5-inch water yields are comparatively small in contrast to yields of 12 to 25 inches from the high-altitude subalpine forests, but are important to development along the Front Range. Watershed management practices can be expected to provide practical alternatives for increasing water supplies.

Keywords: Coniferous forest, forest management, range management, vegetation effects, ponderosa pine zone, watershed management, land use planning.

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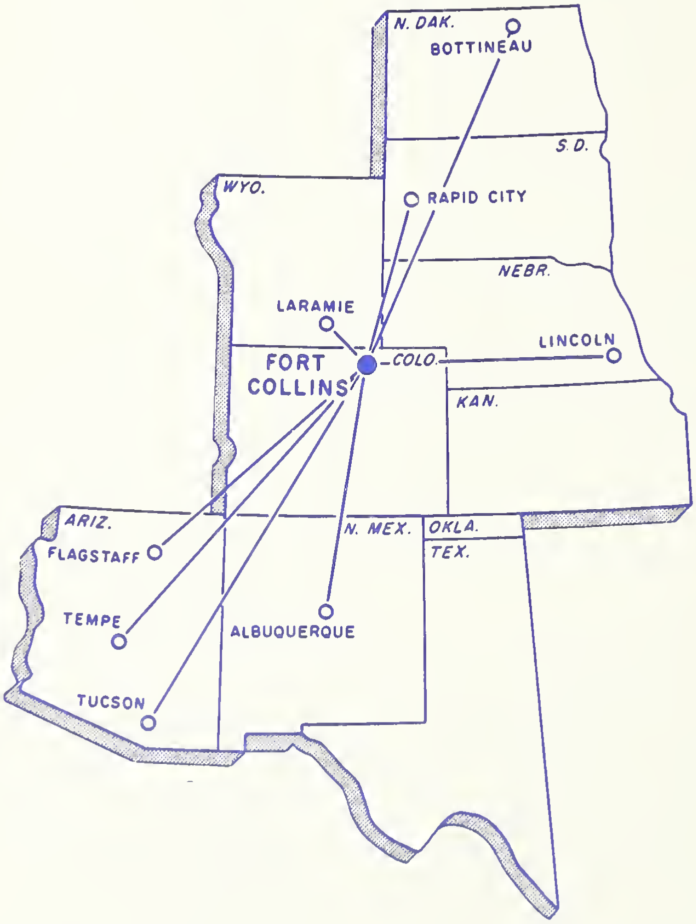
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